PREPARATION OF THERMOPLASTIC CONTAINER VIA THERMOFORMING PROCESS

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ABSTRACT

Thermoforming process is one of the processes used in fabrication of plastic part. Thermoforming process is a process of changing flat thermoplastic sheet to three dimensional shapes. The type of thermoforming process used in this project is vacuum forming. Thermoforming process rarely used in industry of fabrication thermoplastic container. Thermoplastic are plastic that softened and can form any shape using heat and its return to a solid upon cooling. The thermoplastic material type used in this project is Polypropylene (PP). The properties of this (PP) material are economical material, good and resistance to fatigue. Therefore, the main objective of this study to prepare the thermoplastic container by using thermoforming process. In preparation of this thermoplastic container, the design and fabricate the mould is the important process to produce good container. The difference temperature used to identify the suitable temperature used in thermoforming process. The temperature used start with 160°c until 200°c. The result shows the suitable temperature in range 165°c-170°c.

ABSTRAK

Proses Termopembentukan merupakan salah satu proses dalam fabrikasi bahagian plastik. Proses Termopembentukan adalah proses menukar termoplastik rata kepada tiga bentuk dimensi. Jenis proses termopembentukan digunakan dalam projek ini adalah pembentukan berkedap udara. Proses Termopembentukan jarang digunakan dalam industry pembuatan bekas termoplastik fabrikasi. Termoplastik adalah plastik yang lembut dan boleh membentuk apa-apa bentuk menggunakan haba dan kembali kepada pepejal apabila disejukkan. Jenis bahan termoplastik yang digunakan dalam projek ini adalah (PP). Sifat-sifat (PP) ini adalah murah dan beketahanan baik. Oleh itu, objektif utama kajian ini untuk menyediakan bekas termoplastik dengan menggunakan proses termopembentukan. Dalam penyediaan bekas termoplastik, reka bentuk dan fabrikasi acuan adalah proses penting untuk menghasilkan bekas yang baik. Suhu perbezaan digunakan untuk mengenal pasti suhu yang sesuai digunakan dalam proses termopembentukan. Suhu yang digunakan bermula dengan 160^{0}c sehingga 200^{0}c. Hasil daripadakajian yang dijalankan telah menunjukkan suhu yang sesuai ialah di antara 165^{0}c-170^{0}c.

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LIST OF ABBREVIATIONS

PP	Polypropylene
Catia	Computer Aided Three-dimensional Interactive Application
ABS	Acrylonitrile butadiene styrene
ASTM	American Society for Testing Materials
CNC	Computer Numerical Control
G-code	G programming language.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, plastic getting more popular among the industry of fabrication container compare to other material because of their properties that are light weight, high wear resistance and easy to fabricate. Most important characteristic of the plastic is a low production cost and this make plastic become more valuable.

Thermoplastic are plastic that softened and can form any shape using heat and it returns to a solid upon cooling. Thermoplastic also called a thermo softening plastic. The most thermoplastic criteria are having high molecular weight. The example of some thermoplastic type is polypropylene, polycarbonate and acrylic.

The thermoplastic material type used in this project is Polypropylene (PP). The properties of this (PP) material are economical material, good resistance to fatigue and also has a high melting point of temperature. The most important, polypropylene (PP) is recyclable and has number 5 as its identification. Polypropylene (PP) is useful for such diverse products as reusable plastic food containers, microwave and dishwasher safe plastic containers.

Thermoforming is the process that used in industry for plastic part. Thermoforming process is a process of changing flat thermoplastic sheet to three dimensional shapes. There are three types of thermoforming process which are vacuum forming, pressure forming and match die forming.

Therefore, the design consideration for thermoplastic container is also important. The design of mould containers needs a practical design so that the container has a good quality, value and the part can be vacuum during thermoforming. The type of material used for mould also may affect the thermoforming process.

1.2 PROBLEM STATEMENT

Nowadays, the plastic container cannot last longer and can be easily leak because of the unpractical design and material used.

Thermoforming process is the process that rarely used in the fabrication of the container compare to injection moulding. The Injection moulding process most uses for fabrication of thermoplastic material, but has high cost of tooling and equipment compare to thermoforming process.

This project built to study about the suitable of PP thermoplastic material as a thermoplastic container fabricates via thermoforming process. Plus, to investigate the benefits of using thermoforming process in preparing thermoplastic container.

1.3 OBJECTIVE

The objectives of this project are:

1. To design and fabricate the mould of the container.
2. To fabricate Polypropylene (PP) thermoplastic container using thermoforming process.
3. To analyse polypropylene container product fabricated via thermoforming process.

1.4 SCOP OF PROJECT

This project used thermoplastic material such as polypropylene (PP) for the preparation of thermoplastic container. This is because the ability of this material which has good impact resistance, high melting point, and cost effective plastic for thermoforming process.

The mould was designed using Catia V5 2013 software and simulated the g-code to generate in CNC milling machine. Based on this software the part can be machined by simulating it to make sure no mistake during machine the part.

The thermoforming process for preparing of PP thermoplastic container as main of this research. Thermoforming process has a low of tooling cost and equipment cost compare to blow moulding and injection moulding. Thermoforming process is selected for fabrication of PP thermoplastic container because thermoforming has less thermal stress compares to injection moulding and compression moulding. Thermoforming process also used in both production operations either high and low volume.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The main role of this chapter is to provide a review of past research and guidelines efforts related to thermoforming process and thermoplastic of polypropylene material. The polypropylene material used over the industry for replacement of expansive grand plastic. This information is important because it will lead to this study applicability till complete. In this research, it's also the best way to guide and face the problem encountered during the completion of this study.

2.2 THERMOPLASTIC

A thermoplastic, or thermosoftening plastic, is a plastic material, a polymer that becomes pliable or mouldable above a specific temperature and solidifies upon cooling [1]. The process that usually used for changing the shape of thermoplastic are injection moulding, compression moulding, and thermoforming process. There are lot of thermoplastic that usually used in the industry nowadays such as; polycarbonate, polypropylene, polyethylene, polystyrene, ABS and more. But, the focus of thermoplastic needs to study is Polypropylene (PP) sheet type.

2.2.1 Polypropylene (PP)

Polypropylene (PP), also known as polypropylene, is a thermoplastic polymer used in a wide variety of applications including packaging and labelling, textiles stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes [2]. There are polypropylene homo-polymer (PP), propylene-ethylene copolymer (PP-C), and propylene-ethylene random copolymer (PP-R) as a main different types of polypropylene which are ordinarily used in plastic containers designed for microwave heating of food.

2.2.2 History of Polypropylene

The history of polypropylene start in 1954 when a German chemist named Karl Rehn and an Italian chemist Giulio Natta first polymerized it to crystalline isotactic polymer. [3] Nowadays, the global market for this material is about 45.1 million tons, which it used in daily product such as; toys, carpeting, laboratory equipment and reusable product especially in containers.

2.2.3 Properties of Polypropylene

The properties of polypropylene make it attractive for a wide range of application, for example, it has high strength, lightness, flexibility, stability, and easy to process. Moreover, it also well suited to recycling while today's it important for environmentally conscious world. [4] Other than that, the properties of this material also can be used to replace glass, metals, cartons and other polymers. The properties include good transparency, heat resistance, low density, high stiffness, chemical inertness, steam barrier properties (food protection) and recyclability. So, a few properties of polypropylene proved that it's suitable to apply in making of food container. The mechanical properties of polypropylene also include such as inexpensive, lightweight engineering plastic is its tensile strength and stiffness. Polypropylene also has high

chemical resistance, high shrinkage, high warpage, high tensile strength and tensile modulus, low elongation, high creep resistance, is able to withstand maximum exposure temperature, and has a high density.

2.2.4 Chemical Structure

Figure 2.1 shows the chain structure of polypropylene. This structure is relative orientation of CH3 on the figure with its neighborhood on the monomers gave a strong effect on the finish polymer ability to form crystals [1].

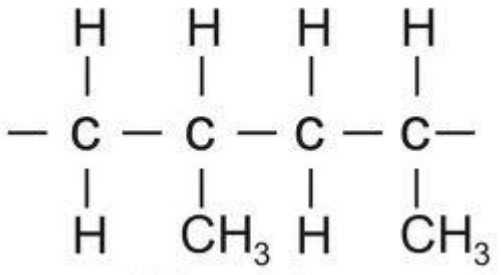

Figure 2.1: Polypropylene chain structure

2.2.5 The Uses of Polypropylene

The polypropylene used in many sectors, among industries nowadays. Polypropylene is processed into film, rigid packaging, consumer products, technical parts and also textiles. The Figure 2.2 shows the percentage of polypropylene used in a few sectors [5].

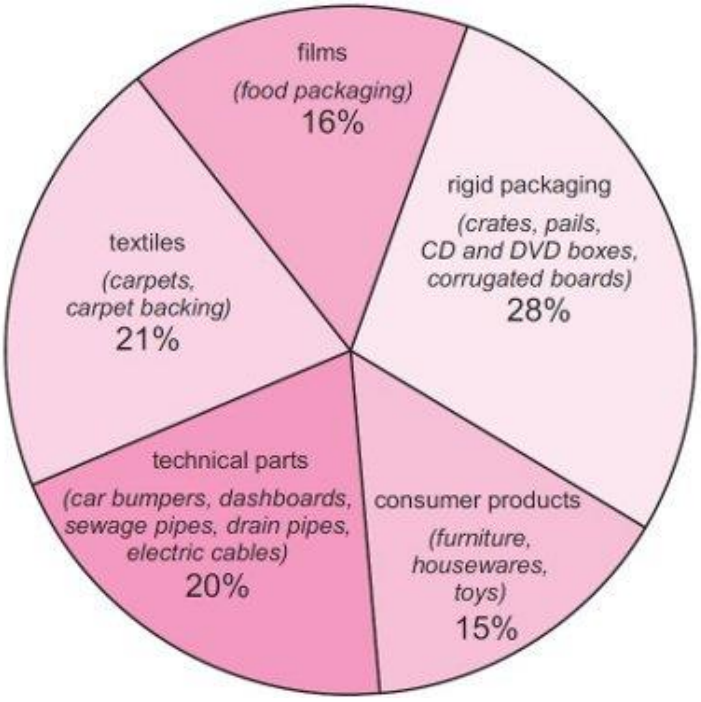

Figure 2.2: The uses of polypropylene.

2.3 THERMOFORMING

The thermoforming process is a plastic process which involved plastic sheet and forming it over a male or female mould. The typical thermoforming process involved with clamping, heating, shaping, cooling and trimming. Thermoforming is a method of manufacturing plastic parts by preheating a flat sheet of plastic to its forming temperature, then bringing it into contact with a mould whose shape it takes [6]. Thermoforming is a relatively simple processing technology. According to McKelvey [7], plastics processing is an operation carried out on polymeric materials or systems to increase their utility. Thermoforming is currently one of the most suitable production technologies for processors in operating industries, as it enables them to release new products in reduced time and with low investments in moulds and equipment [7].

Thermoforming, being the art and engineering of fabricating functional plastic parts from sheet, is maturing into a viable, competitive technology in packaging and structural parts [8].

This process commonly used in making advertising signs, cookie, candy trays and also the packaging. Figure 2.3 shows the thermoforming process for a thermoplastic sheet.

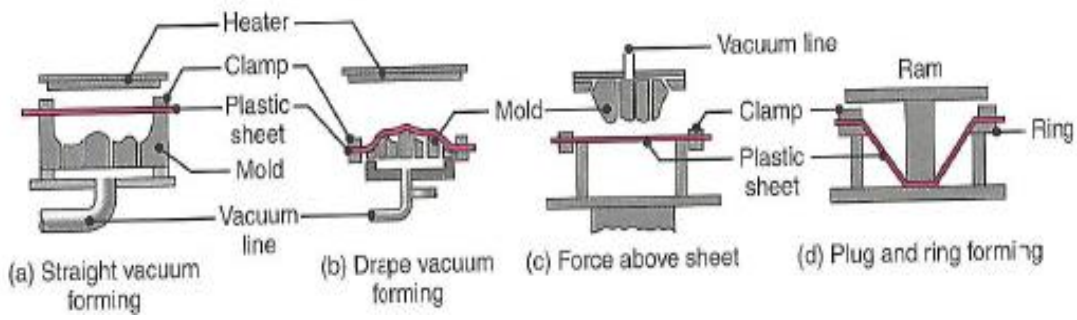

Figure 2.3: Various thermoforming process [8]

2.3.1 Type of thermoforming process

Thermoforming process has three main types which depend on upon pressure, such as vacuum forming, pressure forming and match die forming.

(a) Vacuum forming

During the vacuum forming process, the vacuum pressure is applied to form the thermoplastic sheet into the desired shape by applying heat. Then, the thermoplastic sheet is put on the mould surface. Clamping unit is used to fix the thermoplastic sheet on the mould surface. After that, vacuum is applied quickly after the sheet heated to soften. A surge tank is put-upon to pull the air out between the sheet and mould cavity. Last but not least, the shaped part is cooled before it ejected from the mould cavity. The Figure 2.4 shown the vacuum forming process [9].

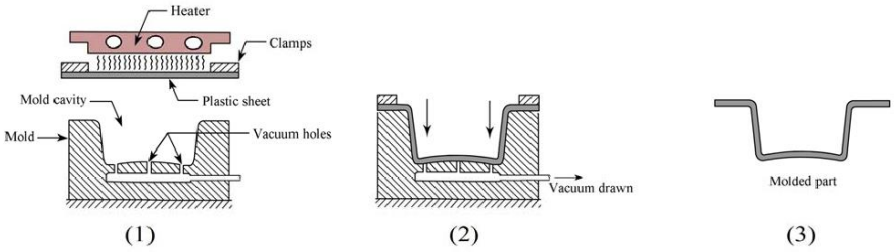

Figure 2.4: The vacuum forming processes

(b) Pressure forming

Pressure forming nearly relates to vacuum forming, but the air pressure needed much higher than the vacuum forming. Next, the preheated plastic sheet is placed on the mould surface and then air pressure is applied above the sheet as shown in Figure2.5. In between the soften sheet and the pressure box, the high pressure is developed. In a few second, high pressure can cause the preheated plastic sheet to deform into the mould cavity. The formed sheet is held in the mould cavity for cooling about few seconds. Lastly, after the part moulded solidifies the part ejected from the mould cavity [9].

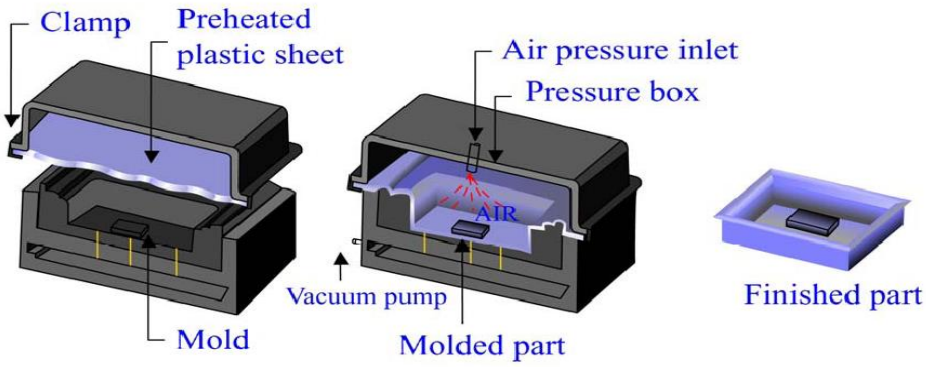

Figure 2.5: The pressure forming process

(c) Match die forming

This process also named as mechanical forming. The mould consists of two parts which is punch and dies as shown in Figure 2.6. In order to soften the thermoplastic sheet, application of heat is applied to heat the thermoplastic material.

Then preheat sheet is placed into the mould surface (also called die) and through punch pressure is applied on the hot sheet. The vacuum pump is used to evacuate the air in between the die and softened sheet and the plastic sheet follow the mould shape. Last process, the mould is ejected after the formed part is cooled.

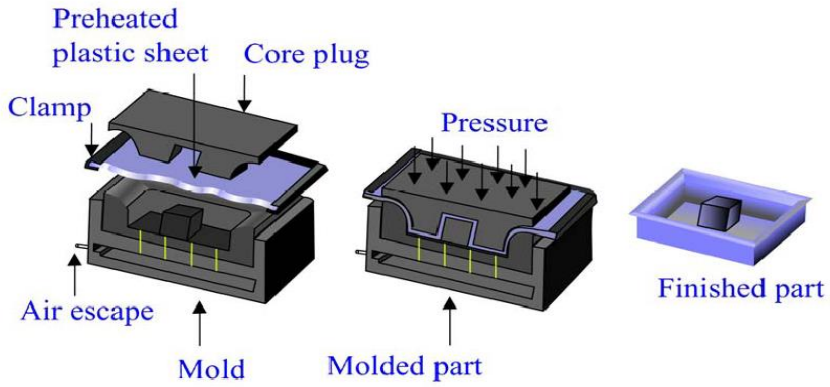

Figure 2.6: The matched die forming process

The most important parameters need to consider during thermoforming process are; mechanical pressure, heating temperature, vacuum pressure, air pressure, heating time, cooling time and also ejection mechanism. The thickness distribution strongly depends on the distribution of the sheet temperature [6].

2.3.2 THERMOFORMING POLYPROPYLENE

Polypropylene for thermoforming usually has a melt flow rate at 230°c. Polypropylene types also include homopolymer which widely used to improve clarity and hardness and for melt-phase processing. Moreover, block copolymer are employed for improved impact strength at low temperature, while random copolymer are selected for high transparency and improved heat sealing quantities.

Otherwise, the polypropylene sheet for thermoforming should be produced with a highly uniform degree of crystallinity across the web. Heating also must be very

uniform, both across and through the sheet thickness. Preheating is carried out at 120˚c and the final forming temperatures depend on whether solid phase or melt phase processing is being undertaken. Plus, 155˚ to 165˚ is the comment range for solid phase forming to unfilled grades of polypropylene, with 160˚ as the optimum. Table 2.1 is about the requirement for the forming properties depending on the grade [9].

Table 2.1: The solid phase forming condition picked types of polypropylene

Polypropylene type	Forming temperature range (°c)	Optimum forming temperature (°c)	Minimum is forming strain (%yield)	Maximum forming strain (%break)	Forming cycle time for 0.05in thickness (Sec)
Homopolymer	160-170	160	24	3360	28
Homopolymer, 105 calcium carbonate	155-165	160	23	3280	22
Homopolymer, 30% calcium carbonate	150-165	160	21	3190	14
Copolymer	155-165	160	22	3360	26
Copolymer, 10% calcium carbonate	150-165	160	23	3180	22
Copolymer, 30%calcium carbonate	130-155	150	80	1500	30

Recent experimental studies confirm that, even with Homopolymer, polypropylene, well-controlled thermoforming conditions allow to form deep cups with good properties such as; processing cycle time, thickness distribution, transparency, and mechanical properties. The optimizations must become more efficient because it is

easier to quickly test different tool designs, process parameters and polypropylene grades.

Another experimental study is about the time-dependent temperature distribution of the total seats in the storing stage was studied for investigating the real status because the temperature distribution of the total seats after the storming stage is the initial temperature of the heating process [6].

2.4 MOULD DESIGN

There are some basic thing needs to consider in manufacturing moulds. First, the flat surfaces should be avoided because dish result may cause the sheet to stretch over the entire surface. While, the curved surface prevents the slight bumps that usually may appear in flat section. The maximum diameter required for vent hole can verify based on sheet thickness and materials used.

The used of undercut in the mould required them to provide a means to easily remove the formed product. Then, to disassemble and permitting the removal of the product, split section moulds can be designed. Careful design and manufacturing planning are necessary to assure proper channels for cooling water are core in the mould. In the design of mould, consider using the largest cavity draft angle because the larger make it better for the formed product removal. The guide for draft angle is at 2˚ to 3˚ per side for female mould and 5˚ to 7˚ for male mould [9].

2.4.1 Type of Thermoforming Moulds

There are few types of mould used in thermoforming process such as wood patterns, cast aluminium mould and machine aluminium moulds.

Wood patterns are the first type of the mould used in thermoforming process. Wood choose because it’s inexpensive and the design easily to make change. Usually, wood pattern are used to gauge general functionality of both the part and the thickness of the material [10].

Cast aluminium moulds are cast at a foundry and typically have temperature control lines running through them. This type of mould helps to regulate the heat of the plastic as speed up the production process. However, this type of mould is cost.

Machined aluminium moulds are like cast aluminium but it cut out the block of aluminium using CNC machine and some programing. Typically machined aluminium is used for shallow draw parts out of thin-gauge material. Applications may include packaging as well as trays [10].

2.5 THE COMPARISON BETWEEN THERMOFORMING PROCESS AND INJECTION MOLDING

Thermoforming process is a plastic production process that two dimensional rigid thermoplastic sheet and uses vacuum to form a sheet into three dimensional shapes like container. Furthermore, thermoforming is a single side process which it is only one side of the sheet can be controlled by the tool surface.

At another point, plastic injection moulding also can be used to produce similar application, but the difference is the cost of tooling more high than thermoforming process.

Thermoforming process has low production cost compared with injection moulding and blow moulding process. The reason is it lower forming and mould capital investment, less development time and cost and redecorating of sheet before forming. Table 2.2 shows the factors consider when comparing thermoforming and injection moulding process.

Table 2.2: The factor consider between thermoforming and injection moulding process.

	Thermoforming	Injection moulding
Material cost	Higher (sheet costs more than resin)	lower
Quantity	More (considerable waste, up to 40%)	Less (little waste)
Machinery cost	Lower than injection moulding	Higher than thermoforming
Trimming equipment	Relatively high	negligible
Production flexibility	Very high	low
Setup time	Very short	Up to 4 times as long as in thermoforming

2.6 SUMMARY

Thermoforming process growth in industry today at least 8% per year in united states, about 45% in Europe, and about 100% in pacific.

There are two aspects that make this process growth attributed. First, the development of newer process technologies that allows thermoforming to compete with other process like injection moulding and also blow moulding. Second, a general customizing trend in design of industrial products that requires less total part per design that range from small to very large products.

Three dimensional thermoforming solid form plastic provide great variety in size, shape and quantities of marketable products, from millions of ounces-size drinking cup or container to thousands of pickup truck storage wells and so on.